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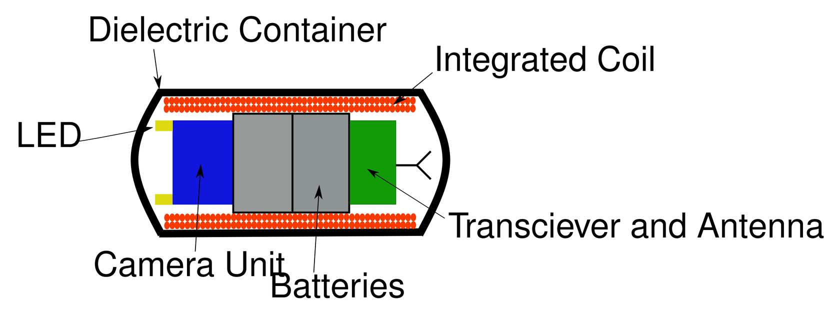
Low-Frequency Magnetic Localization of Capsule Endoscopes with an Integrated Coil

Introduction

Wireless capsule endoscopy (WCE) is an interesting and relevant research topic for diagnosis of the gastrointestinal tract. A small capsule with an integrated camera is swallowed by a patient. For reliable diagnosis and treatment, the accurate location of the capsule has to be tracked during the entire diagnosis procedure of approx. 8 hours. However, the precise localization of an endoscopy capsule is still an open research topic. In this simulation-based study we designed an in the capsule integrated coil, fed with an AC-signal. The generated magnetic flux density was sensed by magnetic sensors arranged in rings around the abdomen. In the proposed simulations, the capsule was localized with an accuracy below 0.5 mm and 0.3 °, respectively. To the best of our knowledge this is the first approach to integrate an active coil into an endoscopy capsule.

Integrated Coil Design

The integrated coil was adapted to the geometric dimensions of commercially available capsules (Fig. 2). Therefore, its length was approx. 20 mm and its inner and outer diameter were 7.9 mm and 12 mm, respectively, leading to a mean coil radius a. The wire diameter of the coil was used as an optimization parameter for the magnetic moment of the coil, which determines the coil resistance R_c, as well as the number of windings N.



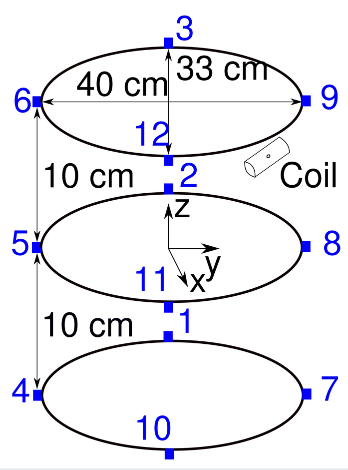
Capsule with its main components and the integrated coil is wrapped around.

Since the battery shell is ferromagnetic, it is magnetized in the presence of the coils field. The overall magnetic moment M is given as:

$$m = I \cdot N \cdot a^2\pi + \int_{V_{\text{bat}}} M_{\text{bat}}\, dV = U_{\text{c}} \frac{N \cdot a^2\pi}{R_c} + \int_{V_{\text{bat}}} M_{\text{bat}}\, dV. \quad (1)$$

Since the capacity of the capsule batteries is limited, the magnetic moment was optimized by considering the corresponding coil current.

Localization Setup



The localization by using the integrated coil was tested by using the localization setup proposed in [1]. The position of the coil was fixed at (60, 60, 60) mm, while its orientation was varied.

Optimized Magnetic Moment

Magnetic moment m of the coil for different wire diameters and the corresponding coil current. For increased coil current the coil voltage U_c drops due to the battery resistance.

Results and Discussion

The absolute magnetic flux density was evaluated over distance and compared with the sensitivity of geomagnetic sensor RM3100. The magnetic flux density was higher than one order of magnitude for distances smaller than 20 cm from the coil. It was concluded that a coil with a wire diameter of 0.125 mm, resulting in a current of approx. 15 mA would be most sufficient for the localization of the capsule. Since a silver-oxide battery of a capsule is limited to approx. 80 mAh, the capsule can not be localized steadily. By considering the relatively slow movement of a capsule it is a valid approach to localize the capsule only every couple of seconds. The coil was localized by using the magnetic dipole model (Eq. 1) and measuring the magnetic flux density at the 12 sensors. Due to the ferromagnetic shell of the batteries, B was increased by a factor of approx. 2.4. On these values, the Levenberg-Marquardt Algorithm was applied to estimate the position and orientation of the coil. The mean position and orientation errors for the coil are presented in Tab. 1.

Table 1: Position P_{err} and orientation O_{err} errors and their mean values. A coil with d_w of 0.125 mm and a ferromagnetic battery shell inside the coil was considered.

	P_{err} in mm	O_{err} in °
Mean value	**0.47**	**0.29**

The achieved localization accuracy is competitive with state-of-the-art magnetic localization methods for WCE. In the future, we will validate the results by experiments.

References

[1] Zeising, S., Ararat, K., Anzai, D., Thalmayer, A., Fischer, G., and Kirchner, J.: Performance Optimization of a Differential Method for Localization of Capsule Endoscopes, in: 7th International Electronic Conference on Sensors and Applications, 2020.